Chapter 3 - Science Overview

3. SCIENCE OVERVIEW

3.1 INTRODUCTION

The FCF is implemented to serve the science community of the United States. For FCF to be successful, that community must perceive a capability that is accessible (friendly), provides quality measurements within reasonable time and cost, and exhibits high levels of utilization for the extended life of the facility.

In this spirit, both near-term requirements (based on existing or proposed experiments and necessary operations) and long-term goals (based on desired capabilities and "enlightened forecasts" of facility operations) are described from the perspective of the science user community. Maintaining this perspective throughout facility development increases the likelihood of having satisfied customers over the next two decades.

The enveloped requirements expressed in this document are evolved from a set of “basis” experiments chosen to represent both near and long-term technical challenges for the on-orbit facility and from a vision of facility operations. It is necessary to consider this total, integrated perspective because the user is impacted by the total system – not merely by the measurement tools.

The initial concept for the total FCF capability must reflect a well-conceived entity that meets the initial hardware requirements and also exhibits the ability to evolve towards less well-defined but ever-expanding capabilities in the future.

The purpose of this section is to highlight those top-level factors which affect the user's perception of the facility and relate them to the requirements called out in this document. The following items are included:

- a vision of the facility in terms of top-level goals (Section 3.2)
- an overview of the basis experiments used to define the technical requirements envelopes (Section 3.3)
- a projection of long-term goals for the facility (Section 3.4)
- a discussion of the interfaces the scientist has to the facility (Section 3.5)
- a discussion of goals for the science selection and support process (Section 3.5.1)

Facing figure shows the organization of this section.

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- Useful
- Accessible
- Cost effective

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3.2 SCIENTISTS' VISION OF THE FACILITY

The science user community should find the facility:

- **Goal GS1 - Capable of high quality measurements** as demonstrated by:
  - meeting all science requirements
  - producing verifiable science measurements
  - ability to reliably meet all facility technical specifications for experiment support and operation
  - implementing state-of-the art measurement techniques
- **Goal GS2 - Useful** as demonstrated by:
  - reliably accommodating a majority of the currently available flight experiments
  - adaptability and flexibility to accommodate innovative future experiment requirements
  - inspiring new users to propose experiments within existing capabilities
  - ability to sustain and expand high levels of facility utilization as Space Station support grows
- **Goal GS3 - Accessible** as demonstrated by:
  - convenience and efficiency of interactions between science teams and the facility
  - minimization of time required to produce quality experimental data for each experiment
  - ability to accommodate existing flight hardware elements, PI-generated hardware and software, and commercial off-the-shelf hardware elements
- **Goal GS4 - Cost effective** as demonstrated by:
  - achieving performance requirements with minimal investment of time and personnel
  - achieving performance requirements with minimal development of new hardware (i.e., optimal reuse of existing hardware)

To attain these goals, the FCF must strive to identify hardware and operations concepts which meet near-term requirements, but do not preclude growth and enhancement of the facility as experience is attained.

Note: See Section 3.3.1 for explanation of numbering system.

Facing figure summarizes the goals stated in this vision.

GOALS FOR THE FACILITY

The FCF shall be:

- √ Capable of high quality measurements
- √ Useful
- √ Accessible
- √ Cost effective

3.3 DEFINITION AND USE OF BASIS EXPERIMENTS

The Fluids and Combustion Facility must accommodate a full range of experiments from two science disciplines (fluids and combustion) which reflect increasingly broad scope in:

- variety of samples addressed
- precision and types of measurements required
- range of dynamics addressed

It is evident that designing one facility to accommodate this breadth of activities is very challenging. Similarly, it is not possible to write a finite set of "facility requirements" which realistically includes all requirements for yet-to-be defined experiments drawn from such diverse science and technology.

To bound the technical realm of this challenging problem, a set of basis (or reference) experiments was identified for each discipline. (The approach for identifying the basis experiments for each discipline and the experiment titles are presented in Sections 3.3.2 and 3.3.3).

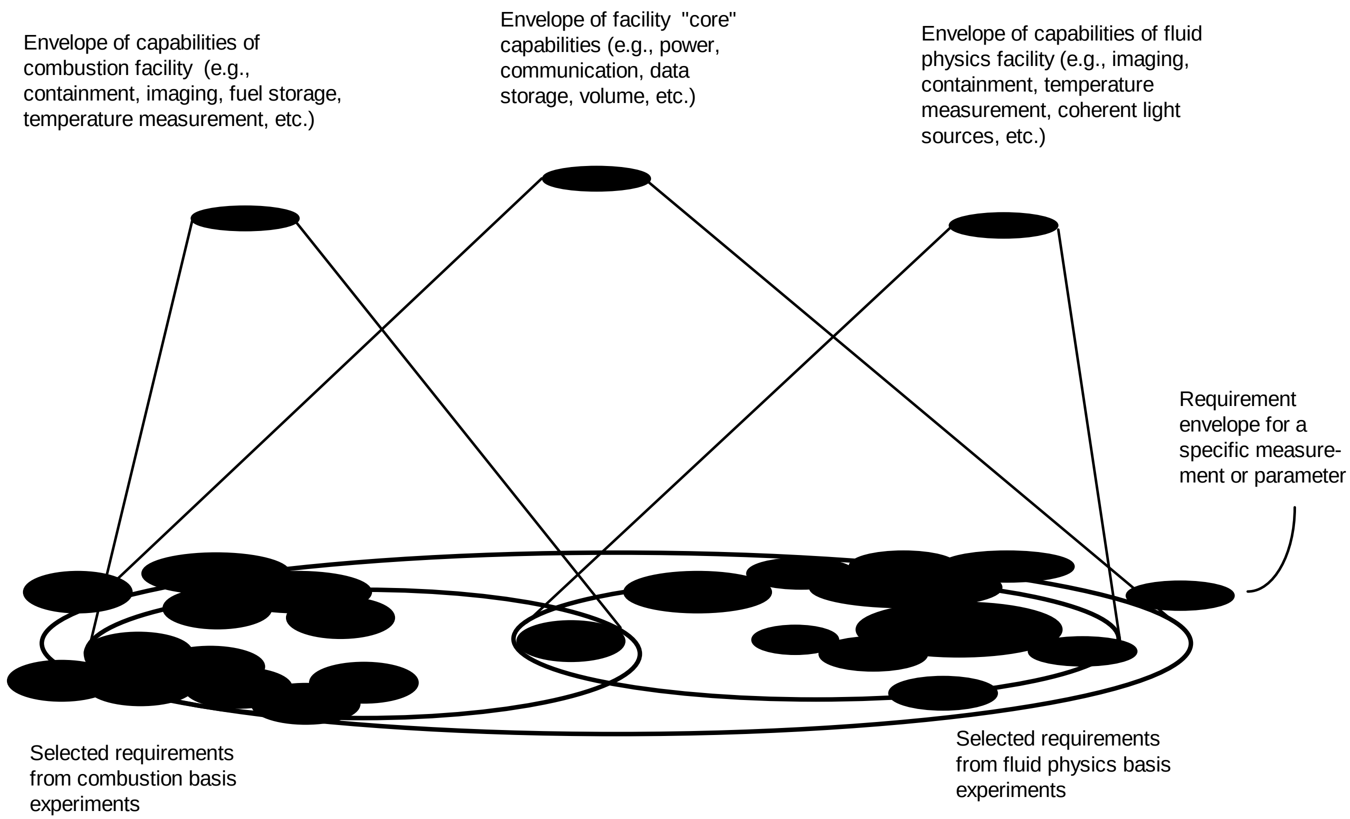
For both disciplines, the science requirements for each experiment were screened to identify common features (key experimental parameters, similar measurement systems, similar spectral requirements for imaging, etc.). Parameters found useful in defining key measurements and operations were selectively cross-plotted to provide performance "envelopes" reflecting the frequency of occurrence and the parameter range within the basis experiments. These envelopes are intended to map out a range of acceptable performance to assign as a facility requirement rather than relying on single point data (which is too often reduced to the "worst case" for each parameter).

It must be emphasized that this document does not and cannot provide detailed science requirements for each experiment. This level of experiment-specific requirements will be levied through individual experiment Science Requirements Documents (SRD). Each SRD will be developed by the experiment investigator and science support team prior to graduation of the experiment into the flight program.

The capabilities defined in this document are expected to provide a facility that is able to accommodate wide-ranging science experiments when augmented with selected pieces of experiment-specific hardware and measurement tools which are unique to individual requirements.

Facing figure displays the concept employed for mapping requirements envelopes for FCF onto selected requirements from the basis experiments.

MAPPING OF FACILITY CAPABILITIES ONTO DISCIPLINE



3.3.1 Screening of Requirements

The technical requirements presented in Sections 4, 5, and 6 of this document have been screened in a manner intended to provide focus on those requirements that have both breadth and content consistent with “facility-level” capabilities being addressed herein.

To be considered a requirement for the facility, it must be that:

- the item is objectively verifiable
- more than one basis experiment can be demonstrated to fail if the requirement is not met.

To assure that many appealing, focused, and emerging capabilities and “experiment-specific” needs are not eliminated from consideration, a process was employed which permits retention of many “better ideas” as:

- “Desires”: not a qualifying requirement, but supported by objective verification that a basis experiment would be demonstrably improved if the desired capability were implemented.
- “Goals”: not a qualifying requirement, but supported by a rational argument clearly indicating that the capability is likely to improve the outcome of a basis experiment.
- “Suggestion”: not a qualifying requirement, but a demonstrated, unique approach or recommendation of “how” to achieve a requirement, desire, or goal.

The primary rationale for this screening is to assure that appropriately well-defined and measurable requirements are placed on the facility. It is not intended to preclude these “better ideas” when explicit benefits are demonstrated.

To facilitate an orderly approach to indexing and tracking the requirements, desires, and goals called out in this document, a set of parallel sequences is employed:

Requirements from Science Overview:	S1 . . . Sx
Requirements from Fluids Envelope:	F1 . . . Fx
Requirements from Combustion Envelope:	C1 . . . Cx
Requirements from Operations Envelope:	O1 . . . Ox

Similar sequences of "desires" and "goals" are identified with an additional letter:

Desires from Science Overview:	DS1 . . . DSx
Desires from Fluids Envelope	DF1 . . . DFx
etc.	

and,

Goals from Science Overview	GS1 . . . GSx

etc.

Suggestions are cited but not numbered.

Facing figure shows the definitions of the screening requirements.

CRITERIA FOR SCREENING FACILITY REQUIREMENTS

Definitions:

- ***Requirement:*** More than one basis experiment can be demonstrated to fail if the required facility capability is not implemented

- ***Desire:*** A basis experiment can be objectively demonstrated to be improved by the capability, but would not fail without the capability

- ***Goal:*** There exists a rational argument that clearly indicates that the capability is likely to improve the outcome of a basis experiment or utilization of the facility

- ***Suggestion:*** A recommendation based on experience in flight or laboratory experimentation of "how" to accomplish a requirement, desire, or goal

3.3.2 FLUIDS BASIS EXPERIMENTS

The technical fluids requirements presented later in this document (Section 4) are based upon a set of reference or “basis” experiments that were chosen to represent a wide range of research interests or sub-disciplines of the fluid physics community. These were based on a mixture of inputs including:

- feedback and experience from Principal Investigators (PIs) in the ground-based science program
- feedback and experience from PIs in the flight program
- documentation from the NASA Microgravity Science program's Fluids Discipline Working Group (DWG)
- discussions with the DWG and other investigators in the field
- science requirements for existing microgravity experiments
- requirements and concepts for proposed experiments chosen from NASA Research Announcements

Fourteen basis experiments were chosen and are described in Appendix A. The set includes at least one representative experiment from each of the sub-disciplines currently included in the fluids program.

These sub-disciplines include:

- capillarity (isothermal)
- colloids
- thermocapillarity
- fluid (including polymers) rheology
- electrohydrodynamics
- multiphase flow
- granular media
- critical fluids (second order phase transitions)
- first order phase transitions
- diffusive phenomena

Facing figure lists the fluids basis experiments. The experiment numbers correlate with the numbering system in Appendix A (example: Sect. A2.14 is experiment f14).

BASIS EXPERIMENTS FOR FLUID PHYSICS

Section#	Exp.#	Experiment Name	Relevant Area
A2.1	f1	Thin Film Fluid Flows at Menisci	• thermocapillarity
A2.2	f2	Contact Line Hydrodynamics	• thermocapillarity
A2.3	f3	Rheology of Non-Newtonian Fluids	• fluid rheology
A2.4	f4	Dynamics of Hard Sphere Colloids	• colloids • first order phase transitions
A2.5	f5	Colloid Physics	• colloids • first order phase transitions
A2.6	f6	Studies in Electrohydrodynamics	• electrohydrodynamics
A2.7	f7	Nucleation and Growth of Microporous Crystals	• first order phase transitions
A2.8	f8	Interactions of Bubbles and Drops	• thermocapillarity
A2.9	f9	Thermocapillary Motion of Bubbles and Drops	• thermocapillarity
A2.10	f10	Interfacial Transport and Micellar Solubilization	• thermocapillarity
A2.11	f11	Thermocapillary and Double-Diffusive Phenomena	• diffusive phenomena
A2.12	f12	Critical Point Phenomena	• second order phase transitions
A2.13	f13	Multiphase Flow Boiling	• multiphase flow
A2.14	f14	Mechanics of Granular Media	• granular media

3.3.3 COMBUSTION BASIS EXPERIMENTS

The technical requirements presented later in this document (Section 5) are based upon a set of reference or “basis” experiments that were chosen to represent a wide range of research interests or sub-disciplines of the combustion science community. Combustion science is composed of a number of different areas of study. Areas that can potentially benefit from microgravity research include, but are not limited to:

- laminar flames
- reaction kinetics
- droplet and spray combustion
- flame spread, fire and fire suppressants
- condensed phase organic fuel combustion (including coal combustion)
- turbulent combustion
- soot and polycyclic aromatic hydrocarbons (PAH)
- materials synthesis
- detonations and explosions

NASA has received proposals from the science community for microgravity research in each of the above areas in response to NASA Research Announcements.

To assure that a representative sample of experiments is considered in defining the facility requirements, a set of basis experiments (see Appendix B) was chosen to span the complement of research interests listed above. The requirements envelope for the Combustion Facility is based upon experiments and supporting information selected as follows:

- Nine peer-reviewed Science Requirements Documents from existing combustion flight investigations
- Two peer-reviewed experiments currently in the flight definition stage
- Experiment descriptions from scientists presently conducting NASA funded microgravity combustion research in the ground-based program
- Feedback from the Microgravity Combustion Science Discipline Working Group (DWG)

This extended path was chosen to avoid "wish lists" within the facility requirements and was endorsed by the Microgravity Combustion Science Discipline Working Group in January 1993 and June 1996: ". . . this is a sound policy that provides reasonable flexibility for treating anticipated combustion experiments while avoiding costs...that might never be needed."

Facing figure lists the combustion basis experiments. The experiment numbers correlate with the numbering system in Appendix B (example: Sect. B2.10 is experiment c10).

BASIS EXPERIMENTS FOR COMBUSTION

Section#	Exp.#	Experiment Name	• Relevant Area
B2.1	c1	Gas-Jet Diffusion Flames	• laminar flames • turbulent combustion
B2.2	c2	Structure of Flame Balls at Low Lewis Numbers	• laminar flames • reaction kinetics
B2.3	c3	Spread Across Liquids	• condensed phase organic fuel combustion • flame spread and fire suppressants
B2.4	c4	Diffusive and Radiative Transport in Fires	• condensed phase organic fuel combustion • flame spread and fire suppressants • laminar flames
B2.5	c5	Smoldering Combustion	• condensed phase organic fuel combustion • flame spread and fire suppressants
B2.6	c6	Droplet Combustion	• droplet and spray combustion • reaction kinetics
B2.7	c7	Laminar Soot Processes	• laminar flames • soot and polycyclic aromatic hydrocarbons
B2.8	c8	Soot Measurement in Droplet Combustion	• droplet and spray combustion • soot and polycyclic aromatic hydrocarbons
B2.9	c9	Unsteady Burning of Contained Reactants	• laminar flames • reaction kinetics
B2.10	c10	Solid Fuels Flammability Boundary	• laminar flames • reaction kinetics • condensed phase organic fuel combustion • flame spread and fire suppressants
B2.11	c11	Radiative Ignition and Transition to Flame Spread	• laminar flames • reaction kinetics • condensed phase organic fuel combustion • flame spread and fire suppressants

3.4 LONG-TERM GOALS FOR THE FCF

The initial configuration of the Fluids and Combustion Facility will reflect predominantly those capabilities required for the initial mix of experiments and selected “generic” capabilities for performing science. It is essential that the FCF operations and hardware concepts exhibit obvious potential for upgrades in technology and performance.

The science community will recognize the obvious benefits of enhanced measurement tools, but the greatest benefits to the science program may well reside in improvements in the efficiency of the development, launch, and flight operations which enable more experiments to be performed.

The following long-term goals are offered as a challenge to the developers to look beyond the initial operation capability:

- **Goal GS5 - Prepare for continual upgrade of capabilities:**
  - Maintain awareness of the evolution of advanced measurement techniques.
  - Cultivate the interest of commercial developers of analytical instrumentation who might provide designs or hardware for the facility.
  - Evaluate each experiment-specific hardware development for broad applicability and implement the hardware for maximum flexibility.
- **Goal GS 6 - Prepare for increased science throughput:**
  - Strive to exceed annual utilization goals within the initial budget; always minimize costs.
  - Identify opportunities to utilize miniaturized electronics for upgrades of the FCF systems to decrease volume and mass required for facility hardware.
  - Continually optimize the repair and replacement operations to minimize down-time and minimize mass/volume displacement of science elements.
  - Be always prepared to utilize all launch and Space Station services made available. The facility should never become the limiting factor in producing additional science data.
- **Goal GS7 - Prepare for international cooperation:**
  - Maintain awareness of hardware capabilities of Space Station international partners to enable efficient support of cooperative interchange of science and instrumentation.
  - Strive to eliminate overlapping capabilities with other Space Station facilities to maximize the unique FCF science return.

Facing figure lists long-term goals for the facility.

LONG-TERM GOALS FOR THE FCF

The FCF should prepare for:

- **continual upgrade of capabilities**
- **increased science throughput**
- **international cooperation**

3.5 SCIENTIST TO FACILITY INTERFACE

The scientists' perception of FCF will be defined in terms of their interactions with the total environment presented by the facility. This environment is conveniently described in terms of hardware, but will be shaped by the facility team members who support its operations and by the facility documentation. The importance of providing consistent, clear, and helpful information and support to the science user cannot be over-emphasized.

The facility will exhibit a complex system of software, hardware, and personnel options to each scientist. The elements of this mix will vary depending on the complexity of the experiment and the sources of experiment systems.

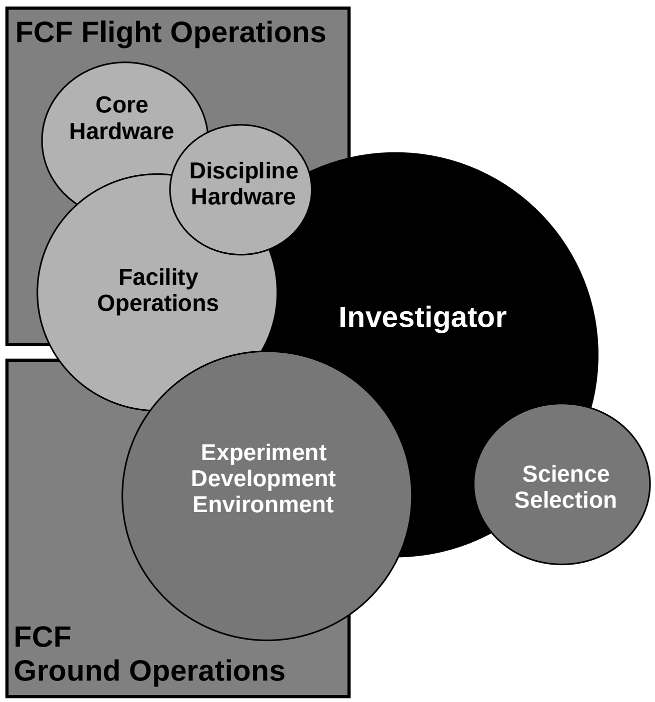
The facing figure depicts a top-level image of the environment within which the scientist operates as he/she participates in the microgravity program. Three principal activities are indicated:

- **Science Selection and Support:** This is the entry to the flight program and is very important to success of the facility, but is not formally part of the FCF process. This interface includes support for experiment definition and resolution of feasibility issues. Due to its importance (and unique character), this interface will be discussed in more detail in the section that follows (3.5.1)
- **FCF Ground Operations:** This interface includes facility support for development, integration, and test of the flight experiment. This is where an approved experiment concept moves into the engineering domain – traditionally the most costly and time-consuming portion of the experiment development cycle, and too often, the least "friendly" interface to the scientist. The facility has the potential to greatly improve the convenience and efficiency of activities involved at this interface. Consequently, this development process is discussed in more detail in Section 6.
- **FCF Flight Operations:** This interface is the "payoff" for the scientist. The experiment is launched, integrated into the FCF, and operated to produce the unique data desired by the science team. This will also be discussed in more detail in Section 6.

The involvement of the scientist in all aspects of the flight experiment process is strongly encouraged.

Facing figure shows the major interfaces the scientist will encounter during the flight experiment development and operations processes.

INVESTIGATOR INTERFACES WITH FCF



3.5.1 SCIENCE SELECTION AND SUPPORT

The initial interface for a typical science user occurs as the investigator is chosen for the ground-based program, proposes a flight experiment, and interacts with NASA scientists and program managers.

Decisions occurring at this interface affect the quality and quantity of science in the program, as well as the level of utilization and extended success of facility.

The focus and scale of the proposed experiments will determine their compatibility with FCF accommodations. In other words, for the FCF to succeed in meeting goals for performance and utilization, the activities which lead to selection and support of flight experiments must be sensitive to the constraints of facility operations on Space Station, and should be positively supported by both the science community and the FCF team.

The facility team can educate and encourage the science community with high quality facility documentation and responsive, supportive interactions.

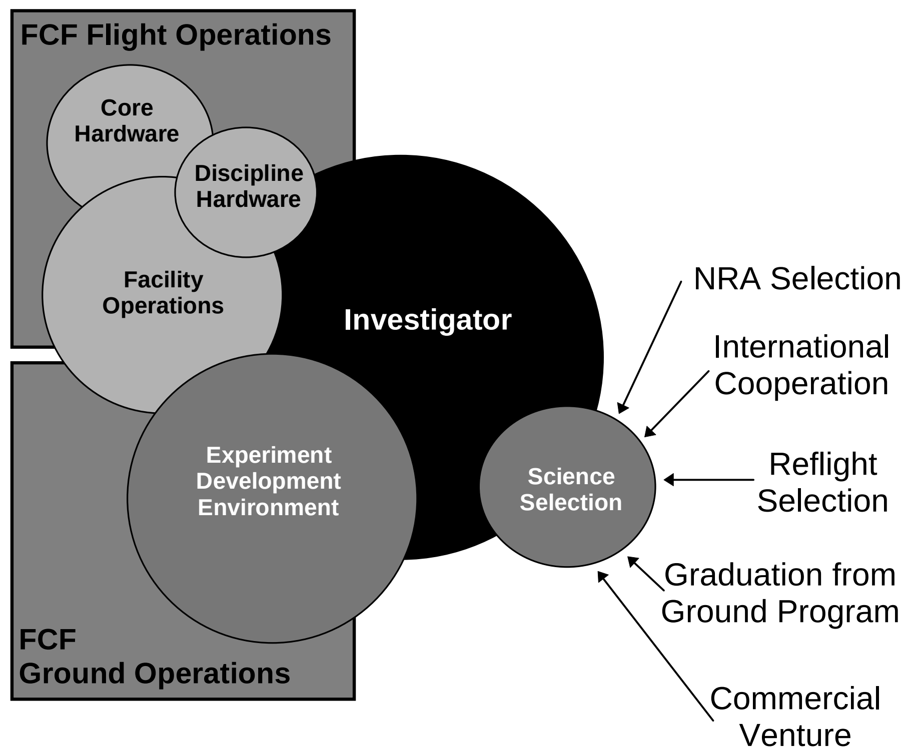
The science community can focus experimental activities in ways that enable experiments of compatible scale and requirements for optimal use of the facility.

If experiments are developed independently from each other, the facility must strive to meet all science requirements, but may fall short of meeting the overall goal for utilization. However, by flying sets of experiments compatible with launch mass, volume, and FCF capabilities, the facility has the potential for optimizing science return for the largest number of investigators.

It is highly recommended that the Microgravity Research Program optimize the selection process to encourage and enable experiment compatability with capabilities of FCF and ISS services

Facing page highlights the science selection interface.

SCIENCE SELECTION AND SUPPORT



3.6 SCIENCE UTILIZATION METRICS

Progress towards the goals stated in Sections 3.2 and 3.4 will be measured relative to actual science productivity of the facility. At this time, the most direct measure of productivity is the number of flight experiments successfully accomplished.

The Microgravity Science program has developed a strong base of support in the Fluid Physics and Combustion communities over the past decade and the program is now poised for the International Space Station era. The level of "premium" flight experiment activity for all carriers is planned to grow to:

~10 PI-experiments per year in FY99

~11 PI-experiments per year in FY01

~14 PI-experiments per year in FY03

The Fluids and Combustion Facility has been expected to accommodate most of this activity and, therefore, to accomplish this plan the facility must exhibit adequate capabilities to implement the exisitng science requirements and adequate flexibility to accommodate yet-to-be-defined experiments.

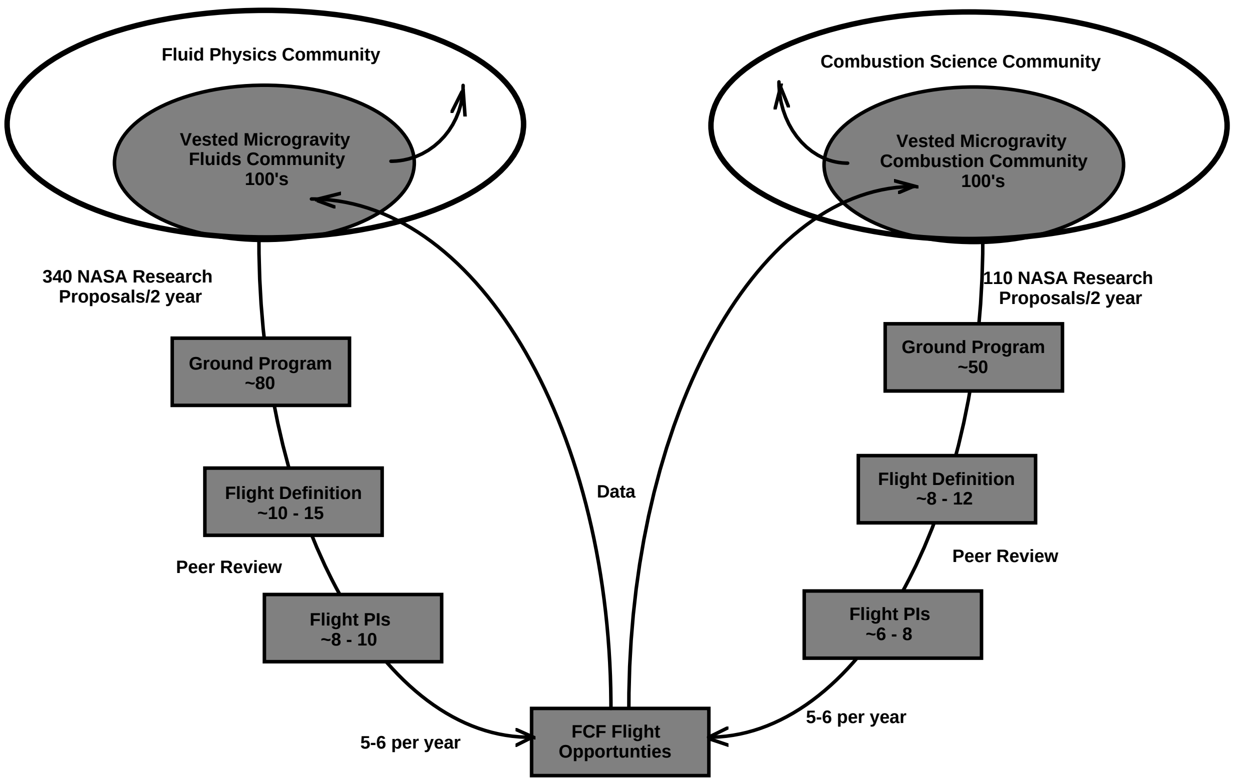
Two classes of experiments will be considered in the evaluation of facility utilization:

- "Premium" experiments are considered to have the scale and complexity of the basis experiments described in Appendixes A and B of this document. This is the class of experiment which has been developed by the Microgravity Science program over the past decade. For the Fluids and Combustion disciplines, these experiments typically exhibit highly integrated diagnostic systems providing multiple high quality measurements in precisely controlled environments.
- "Evolutionary" or "quick-look" experiments are considered to be (typically) smaller scale and less complex experiments. These could represent a subset of the measurements required for a "premium" experiment or use an existing diagnostic capability which partially constrains a required measurement. Ideally, precision would not be sacrificed. In order to best utilize the facility, it will be desirable (indeed, most likely, necessary) to implement experiments within constraints of mass, volume, and cost which may, occasionally, not fully accommodate full implementation of "premium" experiments.

The overall demand for access to space by these disciplines is substantial and reflects a well coordinated experimental program which directly supports important national priorities. It is expected that the facility will enhance access to space and provide the potential to meet and expand the program as the demand increases.

The facing figure shows the numbers of investigators participating in the Fluids and Combustion program at several levels as proposed experiments are screened and developed for flight.

INVESTIGATOR BASE FOR FLUIDS AND COMBUSTION SCIENCE



3.6.1 Fluids Facility Utilization

To meet the demonstrated demand by the Fluid Physics Community and to acheive the programmatic goals to serve this community, it is necessary that Fluid Facility be efficiently implemented and appropriately scaled to accomplish the following:

- **Req. S1:** The Fluids Facility shall accommodate a minimum of 5 to 6 "premium" experiments per year in nominal operations.
- **Des. DS1:** It is very desirable that the Fluids Facility be capable of accommodating many (5 to 10) "evolutionary" or "quick turn around" experiments per year to facilitate optimal utilization of the facility.

3.6.2 Combustion Facility Utilization

To meet the demonstrated demand by the Combustion Science Community and to acheive the programmatic goals to serve this community, it is necessary that Combustion Facility be efficiently implemented and appropriately scaled to accomplish the following:

- **Req. S2:** The Combustion Facility shall accommodate a minimum of 5 to 6 "premium" experiments per year in nominal operations.
- **Des. DS2:** It is very desirable that the Combustion Facility be capable of accommodating many (4 to 8) "evolutionary" or "quick turn around" experiments per year to facilitate optimal utilization of the facility.